SAN ANTONIO

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Gradient Domain High Dynamic Range Compression

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High Dynamic Range Scenes

1/1000

1/500

1/250

1/60

1/30

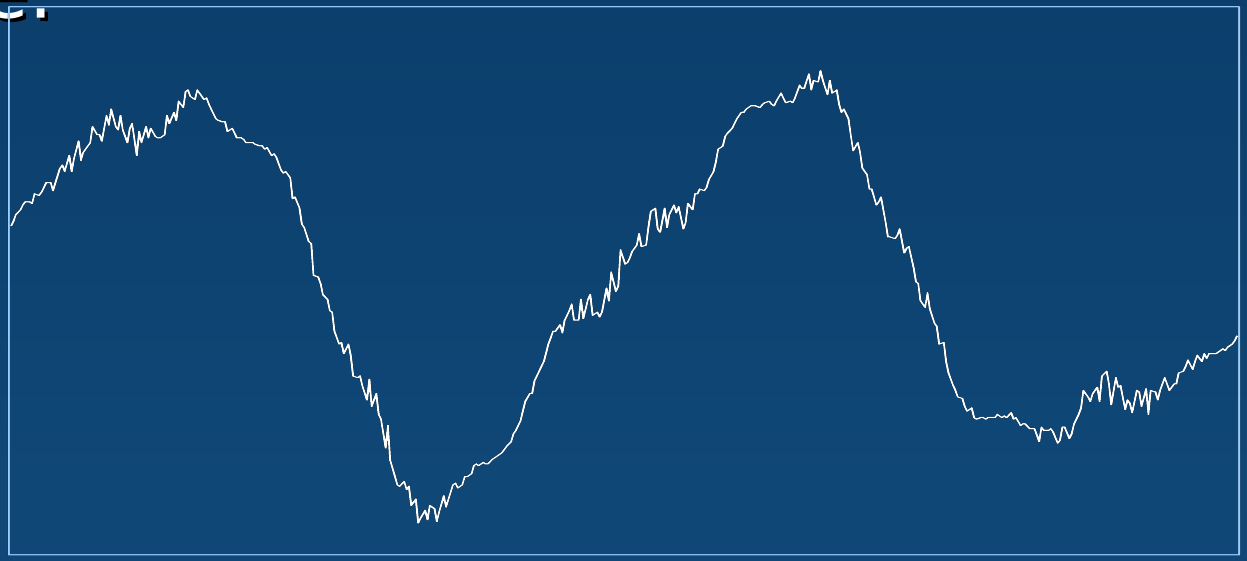
1/15

1/8

1/4

High Dynamic Range Images

- Large ratio between brightest and darkest intensities in the image.
- Small magnitude, local variations in intensity are present across the entire range:



High Dynamic Range Images

Where do they come from?

- Physically-based illumination simulations.
- Digital photography:
  - Combining several differently exposed LDR images into a single HDR image (Debevec & Malik 1997).
  - HDR panoramic video mosaics (Schechner & Nayar 2001).
  - HDR digital cameras.

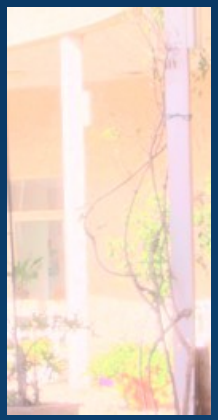
Goal

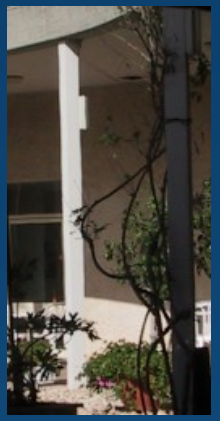
- Compression of dynamic range to enable rendering HDR images on LDR devices.
- Desirable features:
  - Avoid large over/under exposed regions.
  - Preserve visibility of fine details (local contrasts).
  - Avoid introducing artifacts to the image.

Previous Work

- Spatially invariant tone mapping operators
  - Image-independent curves:
    - Linear scaling, Gamma correction, logarithmic mappings…
  - Image-dependent curves:
    - Histogram equalization
    - Visibility matching tone reproduction (Ward et al. 97)
- Problem: monotonic mapping leads to loss of local contrast!

Example: Ward et al 1997





Previous Work

- Spatially variant tone mapping operators
  - Homomorphic filtering (Stockham 72, Horn 74).
  - Retinex-based operators (Jobson et al. 97)
  - Adaptive histogram equalization (Pizer et al. 87)
  - Multi-scale operators (Pattanaik et al. 98)
- Problem: “halo” artifacts

Example: multi-scale operator

Previous Work

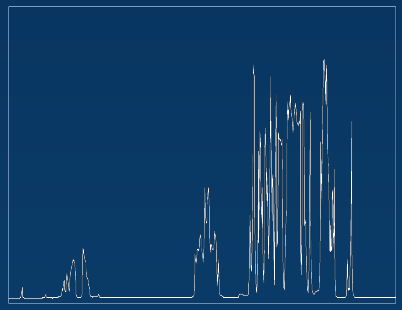
- LCIS – Low Curvature Image Simplifier (Tumblin & Turk 99)
  - Drastic range compression
  - Preservation of visible detail
- Problems:
  - Slow
  - Weak halos, detail over-emphasis

Example: LCIS

Our Approach – Overview

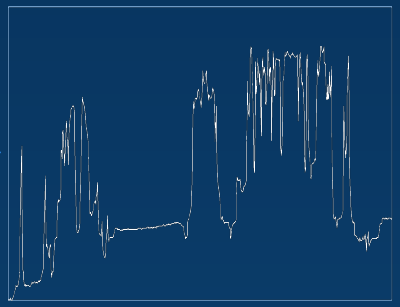
- Observations:
  - High dynamic range results from strong luminance changes
  - Absolute change magnitude is not important
- Method:
  - Examine gradients to identify luminance changes
  - Attenuate high luminance gradients
  - Reconstruct a low-dynamic range image

The Method in 1D

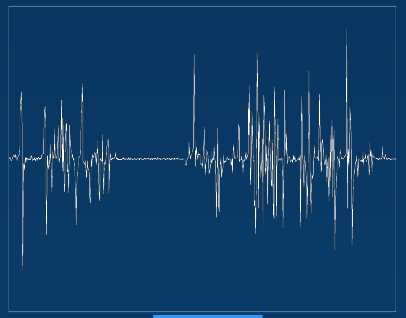


2500:1

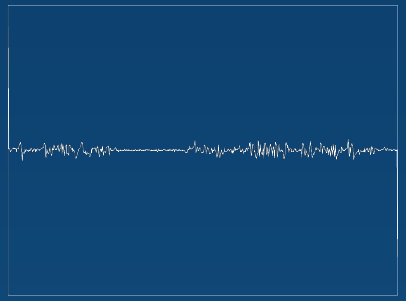
log



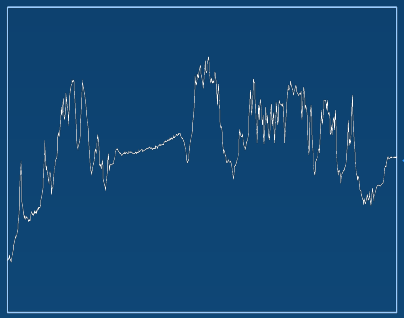
derivative



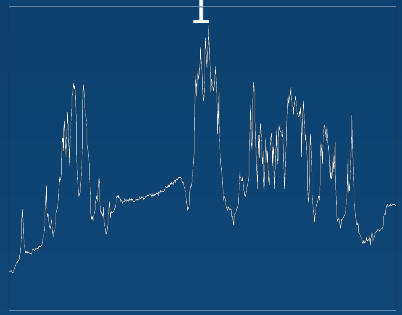
attenuate



integrate



exp



7.5:1

The Method in 2D

- Given: a log-luminance image $H(x,y)$
- Compute an *attenuation map* $\Phi(\|\nabla H\|)$
- Compute an attenuated gradient field G:

$$G(x,y) = \nabla H(x,y) \times \Phi(\|\nabla H\|)$$

- Problem: G is not integrable!

Solution

- Look for image I with gradient closest to G in the least squares sense.
- I minimizes the integral: $\iint F(\nabla I, G)\,dx\,dy$

$$F(\nabla I, G) = \|\nabla I - G\|^2 = \left\| \frac{\partial I}{\partial x} - G_x \right\|^2 + \left\| \frac{\partial I}{\partial y} - G_y \right\|^2$$

Euler-Lagrange Equation

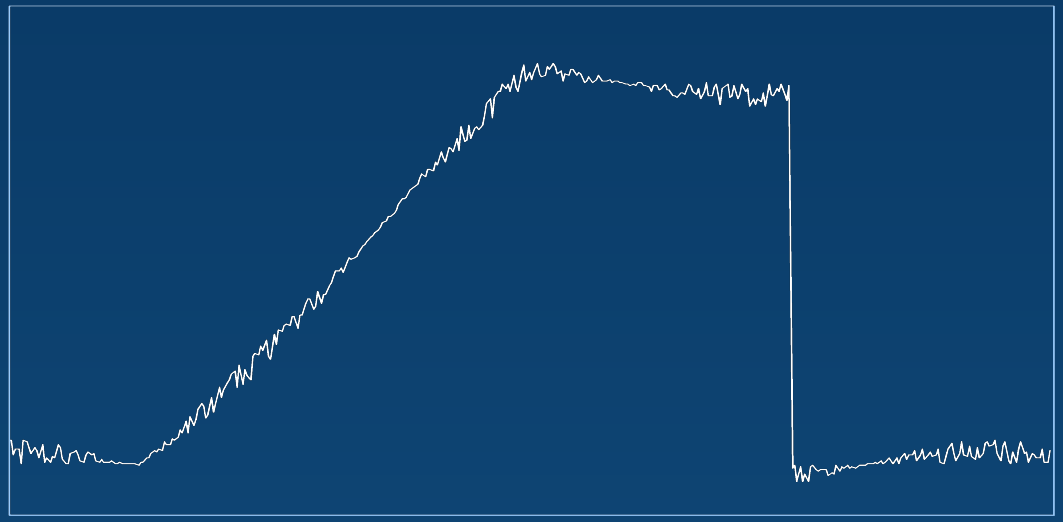
- I must satisfy: $$\frac{\partial F}{\partial I} - \frac{d}{dx}\frac{\partial F}{\partial I_x} - \frac{d}{dy}\frac{\partial F}{\partial I_y} = 0$$
- Substituting F we get:

$$2\left[\frac{\partial^2 I}{\partial x^2} + \frac{\partial^2 I}{\partial y^2}\right] - 2\left[\frac{\partial G_x}{\partial x} + \frac{\partial G_y}{\partial y}\right] = 0$$

$$\nabla^2 I = \mathrm{div} G$$

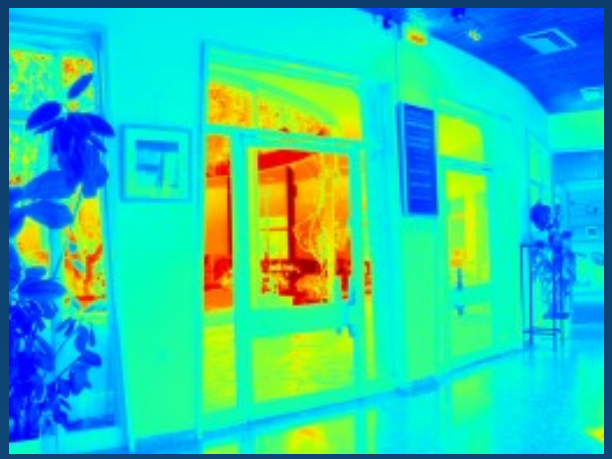
Gradient Attenuation

- Strong luminance changes may occur at different rates:



- Must examine gradients at multiple scales!

Multiscale Gradient Attenuation

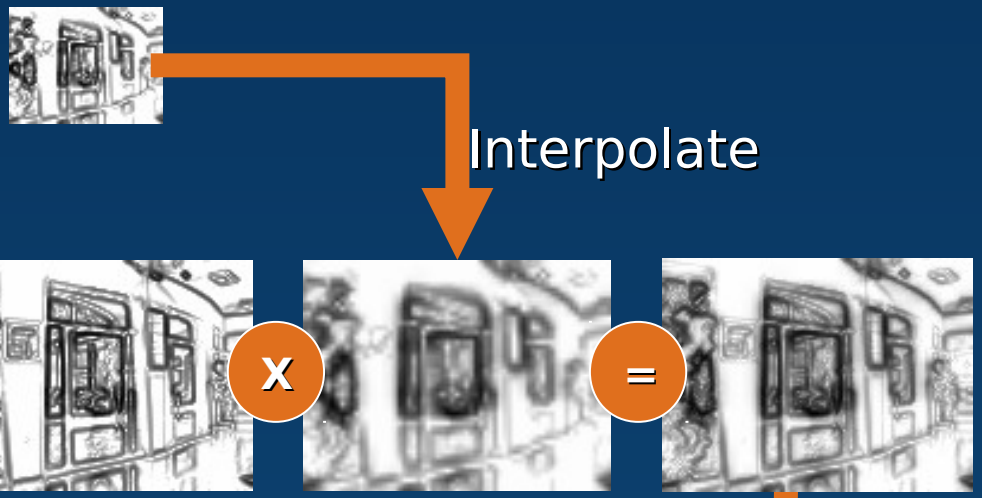


log(Luminance)

Gradient magnitude

Attenuation map

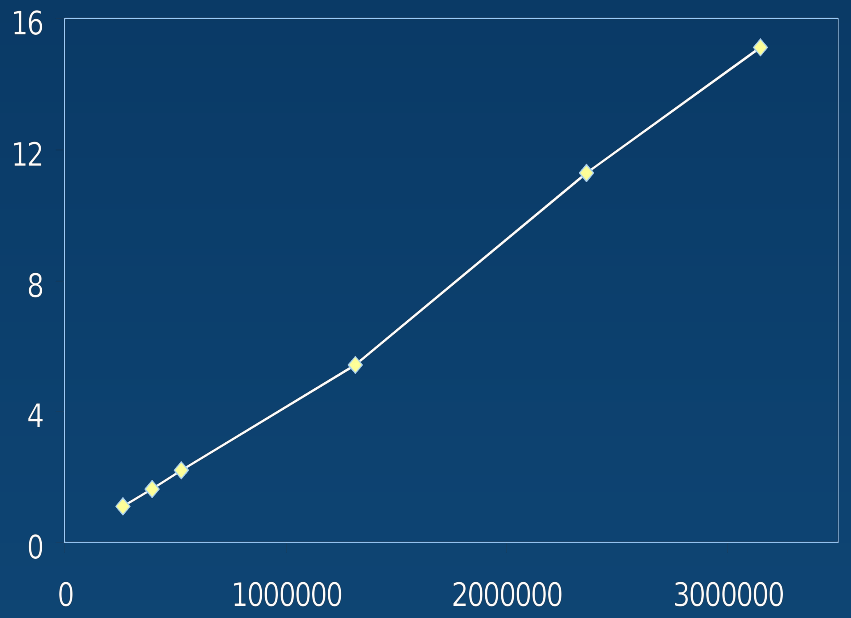
Multiscale Gradient Attenuation



Final Gradient Attenuation Map

Performance

- Measured on 1.8 GHz Pentium 4:
  - 512 x 384: 1.1 sec
  - 1024 x 768: 4.5 sec

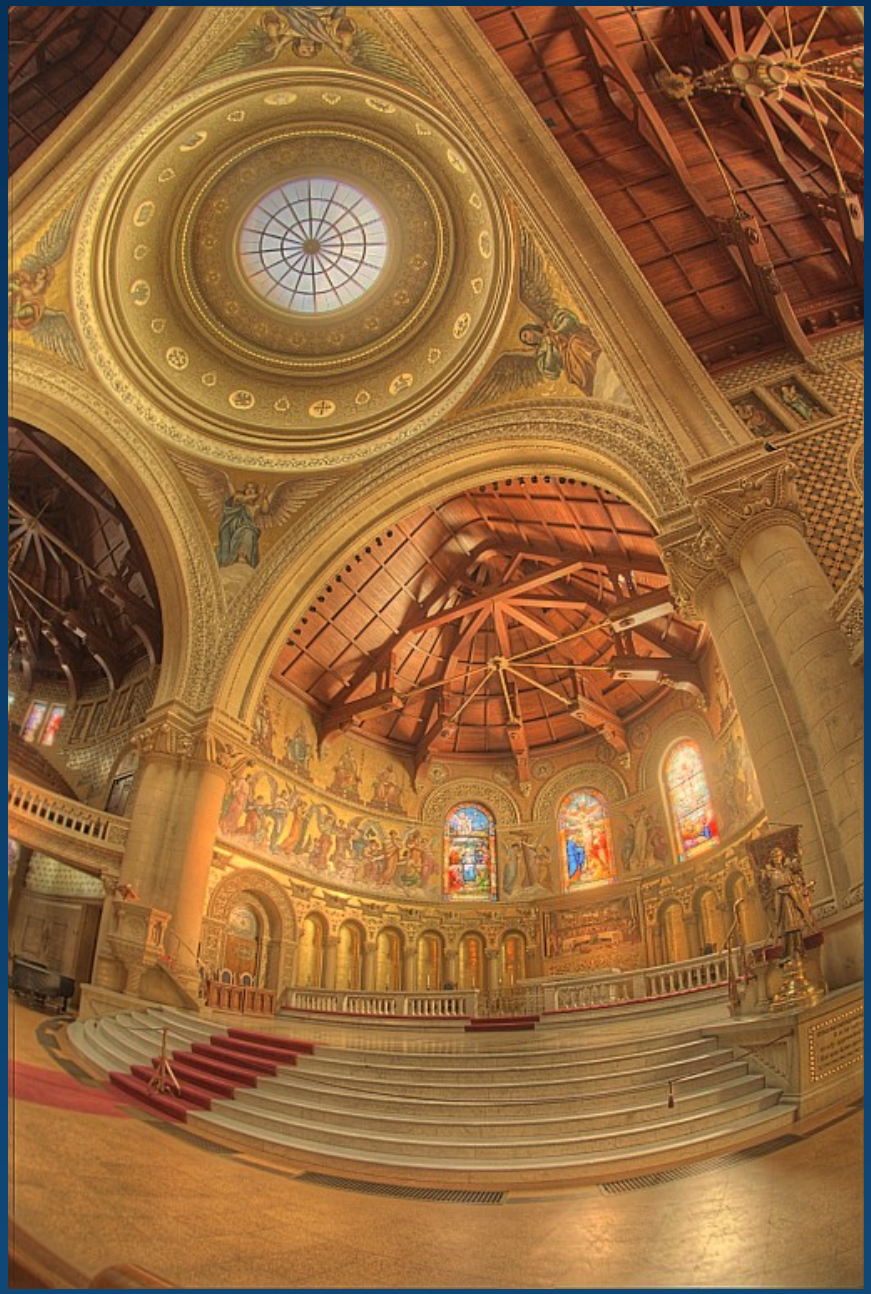


- Can be accelerated using processor-optimized libraries.

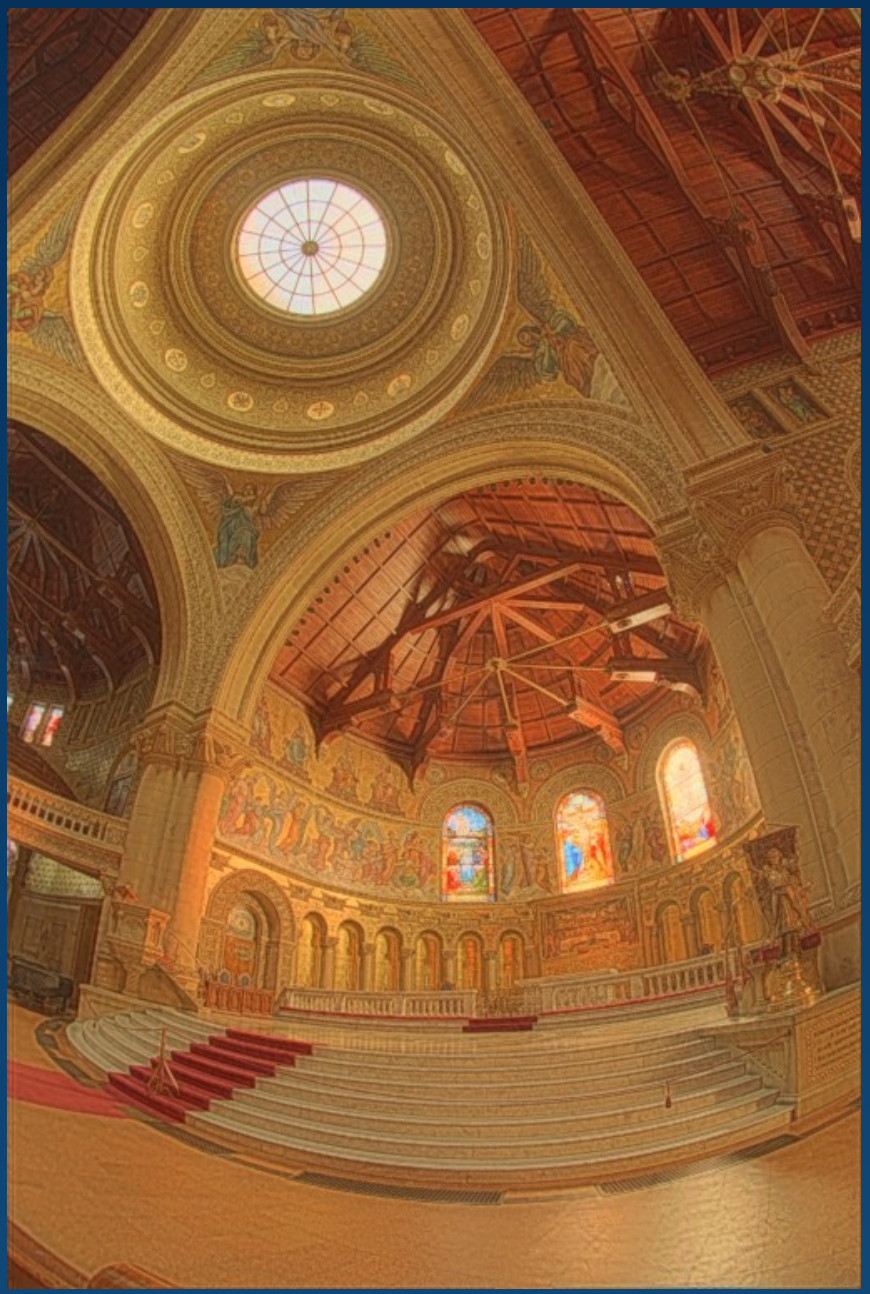
Results (Ward et al. 1997)

Results (LCIS)

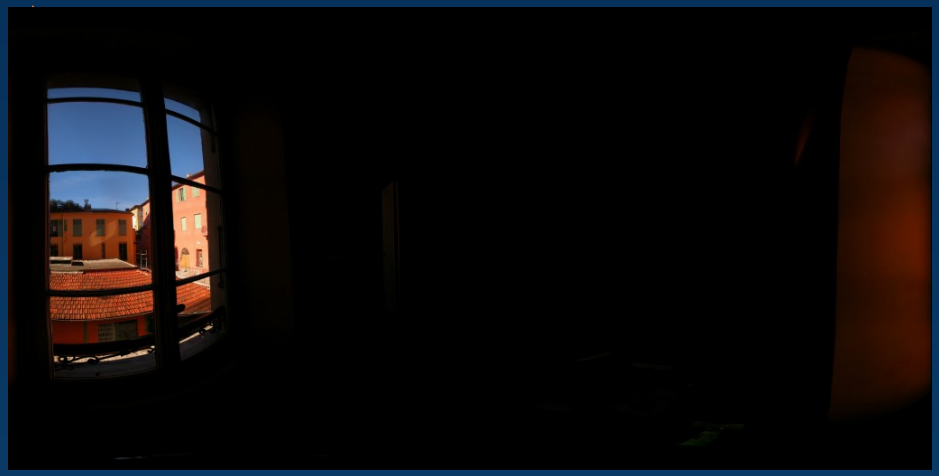
Results (our method)



Our method (2.3 sec)



LCIS (4 min)



Summary

- New method for detail-preserving compression of dynamic range.
- Also useful for enhancing ordinary images.

- Future work:
  - Better handling of color
  - Incorporate psychophysical properties of the HVS
  - Explore other applications of gradient field manipulations.

Acknowledgments

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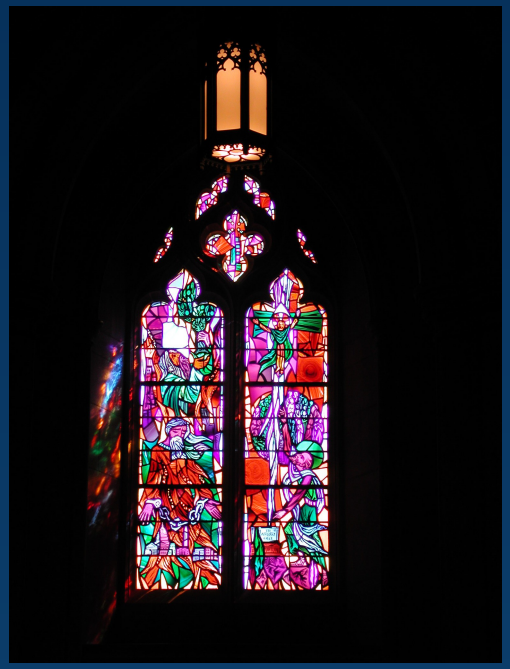

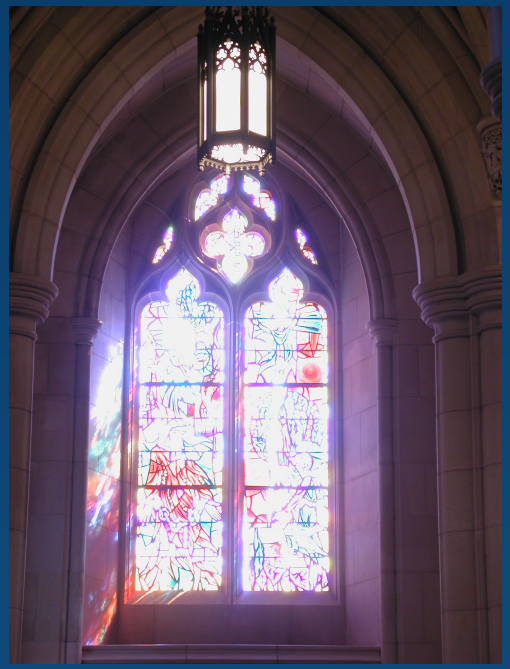

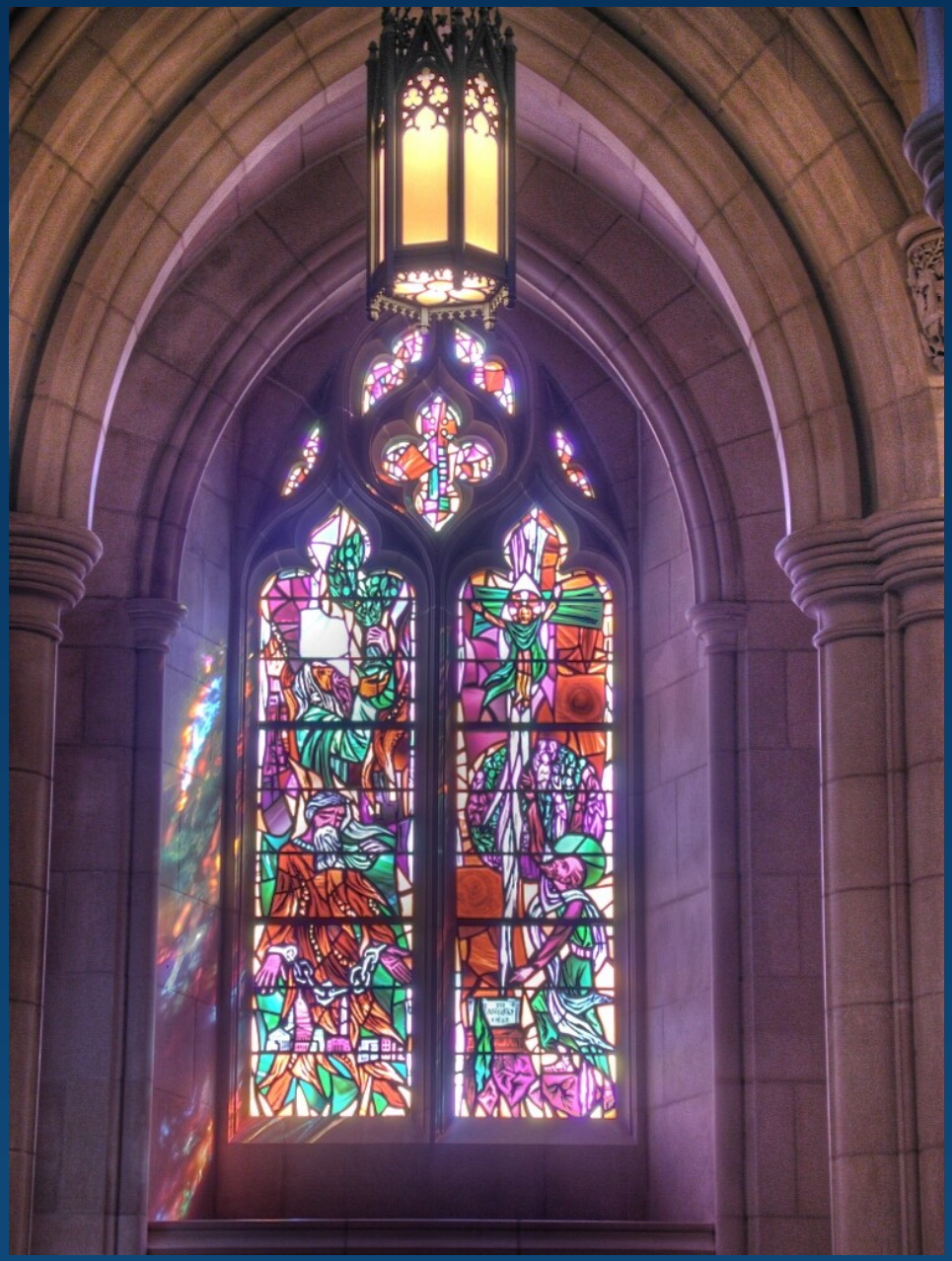

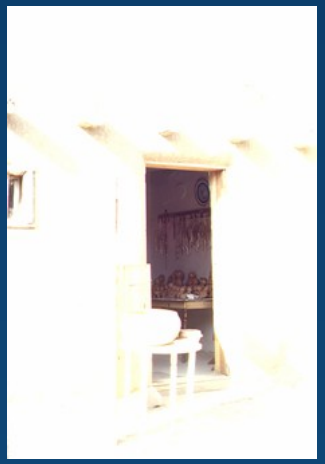

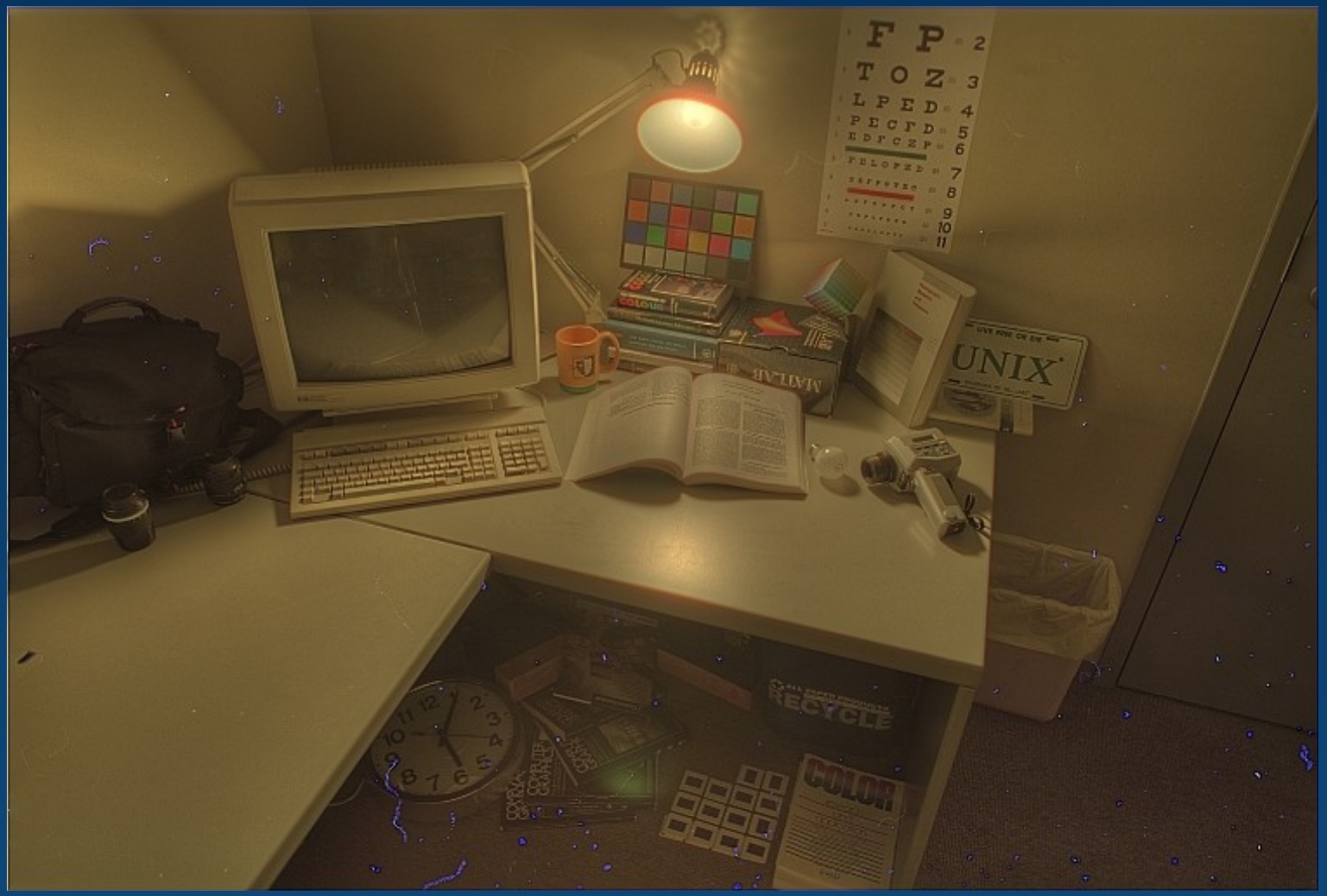
F P
T O Z
L P E D
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COLOR